ERDC/CERL SR-01-17

Construction Engineering Research Laboratory

US Army Corps of Engineers®
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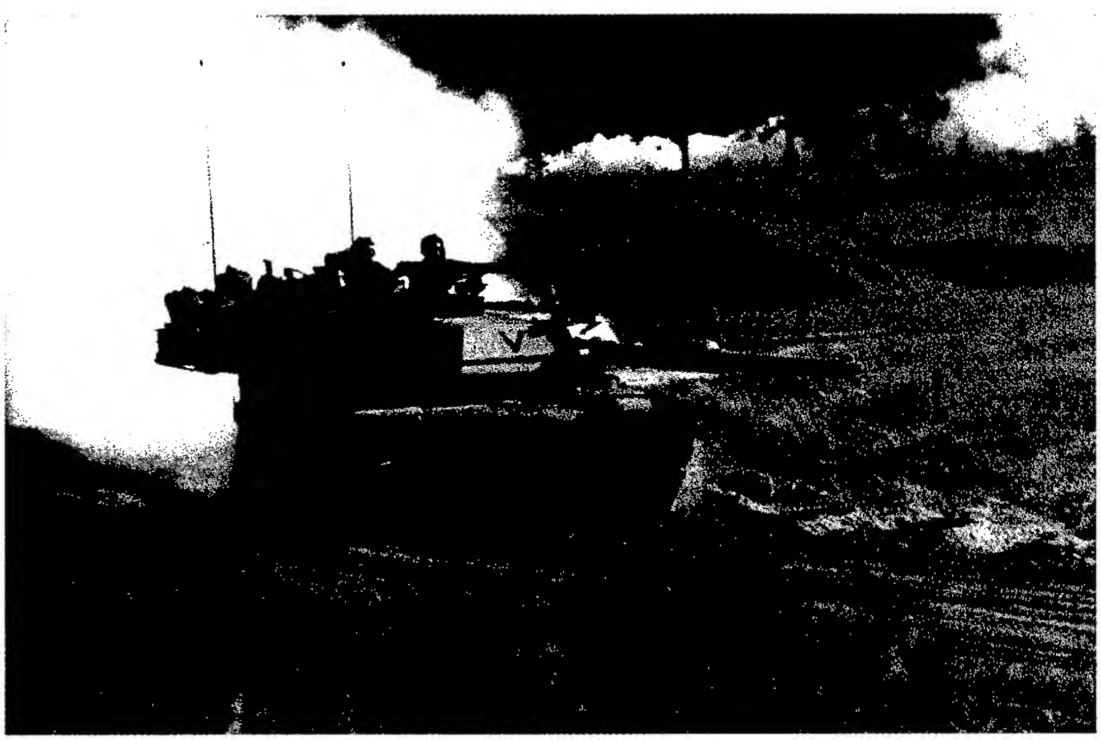
Impacts of Military Vehicle Training Activities on Vegetation: Bibliography With Abstracts

Jeffrey S. Fehmi, Tyrone Farmer, and J. Andrew Zimmerman

August 2001



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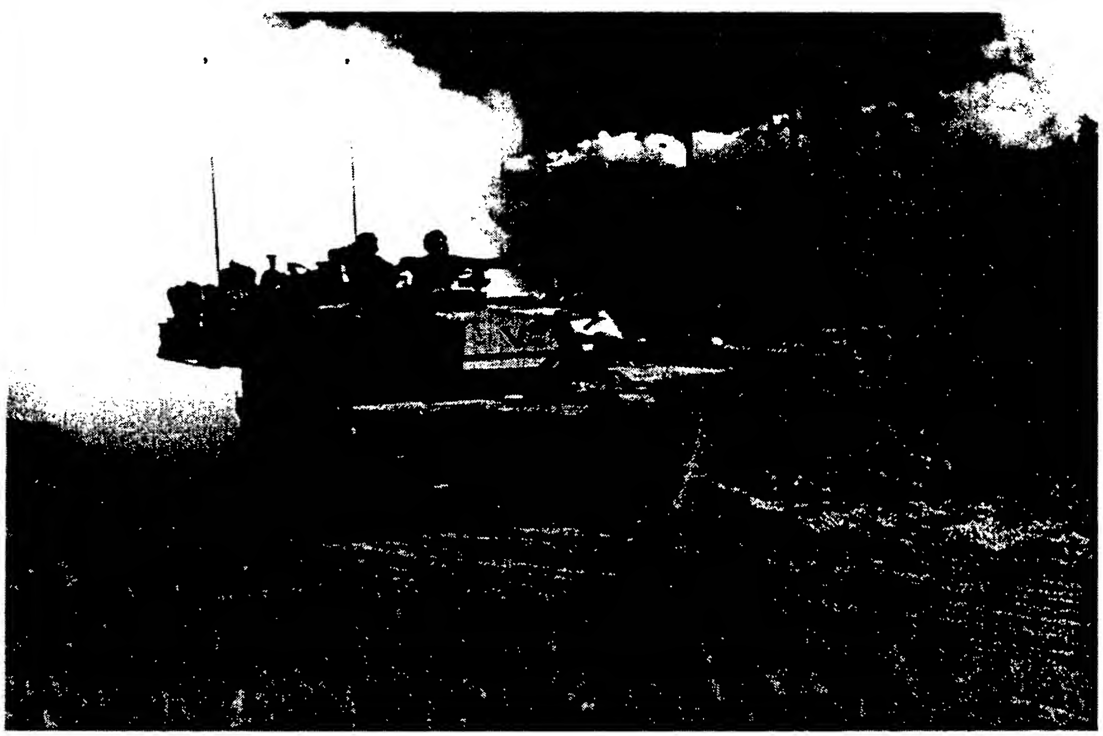

Foreword

This study was conducted for the Office of the Directorate of Environmental Programs (DAIM), Assistant Chief of Staff (Installation Management) (ACS[IM]) under Project 622720896, "Environmental Quality Technology;" Work Unit CNN-T081, "ATTACC/EDYS Integration." The technical monitor was Dr. Victor Diersing, DAIM-ED-N.

The work was performed by the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Dr. Jeffrey S. Fehmi. Part of the work was done by Mr. J. Andrew Zimmerman of the University of Illinois. The technical editor was Ms. Gloria J. Wienke, Information Technology Laboratory. Mr. Steve Hodapp is Chief, CEERD-CN-N, and Dr. John T. Bandy is Chief, CEERD-CN. The Technical Director is Dr. William D. Severinghaus, CEERD-TD. The Acting Director of CERL is Dr. Alan Moore.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL John W. Morris III, EN, and the Director of ERDC is Dr. James R. Houston.

Contents

1 Introduction

Background

Army User Requirements

Documentation of the Army's environmental technology requirements has been an iterative process that began with a series of meetings in 1993 and the Office of the Directorate of Environmental Programs' publication, *U.S. Army Environmental Requirements and Needs*. The Army's environmental technology requirements describe the critical research, development, test, and evaluation needs for accomplishing the Army's mission with the least impact or threat to the environment. These requirements are Army-level requirements that were reviewed for their impacts to readiness and quality of life, impact or threat to the environment, and timeliness needed for the Army to maintain compliance with environmental regulations. All major commands, major subcommands, the Office of the Deputy Chief of Staff for Operations, and the Office of the Deputy Chief of Staff for Logistics were involved in establishing the prioritized and validated list of the Army's environmental technology requirements.

Land Capacity and Characterization is the third priority conservation user requirement. This user requirement defines the Army's need to estimate training land carrying capacity. Twenty-eight exit criteria were identified in the *Land Capacity and Characterization* user requirement. Each exit criteria defines a specific product required to address a specific aspect of the overall requirement. Several of the exit requirements require information on the impacts of military activities and vehicles on installation natural resources. A comprehensive bibliography of current research in this area aids synthesis of the available data and analysis and is important to the success of the project.

Impact on natural resources

To adequately train for combat, military training must occur in all weather conditions and at all times of the year. Training must include digging defensive positions and obstacles as well as breaching adversaries' positions and obstacles. Vehicles must be allowed to maneuver over terrain and distances similar to what is expected in a battlefield environment. Soldiers must be allowed to fire their

weapons and systems in realistic conditions to become confident and capable with their equipment and as a unit. These aspects of military combat training make it unique from natural disturbances in several ways.

The need for trained military forces establishes the training intensity on military lands rather than the capability of the land to sustain training. Other impacts such as grazing or burning are entirely dependent on the quantity and type of vegetation present. Natural grazing pressure will more or less follow the amount of forage available and animal numbers rapidly decline when forage is exhausted. Although it is not military policy, military training could continue until a site consisted of bare mineral soil, though realism would suffer. Disturbances from grazing by domesticated animals (e.g., cattle) are also well linked to vegetation quantity and quality, because profitability declines well before forage availability reaches critically low levels. Fire is similarly linked to ecosystems' vegetation properties. When and where there is little vegetation, fire cannot spread or be sustained.

Grazing and fire are also usually better distributed across the landscape than military training. Domestic grazers select more palatable, available, nutritious, and digestible vegetation over other plants and move across the landscape searching out preferred plants. The effect of disturbances on vegetation ranges from plants flourishing to the opposite extreme: their death and removal from the system. Training exercises can be limited to certain areas where visibility and line of sight are not hindered or concentrated on areas with strategic or tactical advantages. This uneven use pattern may leave some areas with properties more characteristic of plowed fields while leaving adjacent vegetation untouched. Similarly training during dry weather may create little disturbance while the same exercise during wet weather might remove vegetation and compact or turn the soil.

Objective

The objective of this project is to collect published articles, reports, and papers describing known impacts on vegetation resulting from military vehicular traffic in training or simulated training scenarios.

Approach

We surveyed the available literature from sources such as the Web of Science (http://www.webofscience.com [subscription required]), Current Contents

(http://www.isinet.com), and the Scientific and Technical Information Network (http://stinet.dtic.mil) to identify those works applicable to impacts of military vehicles on military lands. The focus was to particularly identify the information available for vegetation as distinct from those concerning air quality, water quality, noise pollution, soil contamination, and direct impacts on animals. However, some literature on animal effects was included because the animal effects were linked to habitat changes and thus discussed impacts of training on vegetation. This link seems to be an area with much potential for future work because the presence or behavior of animals may be able to represent the system properties better than we are able to determine from direct sampling of the vegetation.

The section identified as military references (starting on page 13) contains the works where the authors used observations and research arising directly from military vehicles or military lands. The section identified as supporting references (starting on page 31) contains works not developed from military equipment or lands but which appears applicable to military training activities or vehicles. Also included in this section are derivative military references, those that do not directly report observation or research data, but discuss land management systems or synthesize previously reported data.

There are a number of ways to find out more about the publications and reports shown here. The reports listed as specific ERDC or CERL Technical or Special Reports are available through your installation library or information management office. Many of these reports are also posted on the ERDC/CERL website (http://www.cecer.army.mil/) where they are listed by report number or author. Customers outside the Department of Defense should contact the National Technical Information Service at http://www.ntis.gov.

Scope

The literature review is not limited to any region or country but is constrained by the available documented information base. As with all bibliographies, new references become available even as the publication is being printed. We welcome your suggestions. Please email us at jeffrey.s.fehmi@erdc.usace.army.mil.

Mode of Technology Transfer

This report and the information it contains are made available to military land managers and research personnel as the primary intended audience.

This report will be made accessible through the World Wide Web (WWW) at URL:

http://www.cecer.army.mil/

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Prose	1985	Persisting Effects of Armored Military Maneuvers on Some Soil of the Mojave Desert	17
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Shaw	1989	Evaluation of the Effects of Military Training on Vegetation in Southeastern Colorado	22
Shaw	1990	Tracked Vehicle Impacts On Vegetation at the Pinon Canyon maneuver Site, Colorado, USA	23
Thurow	1993	Tracked Vehicle Traffic Effects on the Hydrologic Characteristics of Central Texas Rangeland	24
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Barret	1975	Disturbance and the Successional Response of Arctic Plants on Polar Desert Habitats	34
Bliss	1972	Plant Community Response to Disturbances in the Western Canadian Arctic	35
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Diersing	1988	A Users Guide for Estimating Allowable Use of Tracked Vehicles on Non-wooded Military Training Lands	41
Diersing	1992	U.S. Army Land Condition Trend Analysis (LCTA) Program	42
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Price	1997	The U.S. Army's Land-Based Carrying Capacity	51
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Whitecotton	2000	Impact of Foot Traffic from Military Training on Soil and Vegetation Properties	60
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4 Military Reference List

1. Ayers, P.D., "Environmental Damage from Tracked Vehicle Operation," *Journal of Terramechanics*, vol 31, no. 3 (1994), pp 173-183.

Soil surface forces resulting from traffic from tracked vehicles can cause environmental damage by decreasing plant development and increasing erosion. This paper investigates the soil surface disturbance from tracked vehicle operation. Sharp turns (lower turning radius) from M113 operation produce increased disturbed widths and more severe vegetation damage. The pad-load ratio for the M113 track shoe was determined at various loads. The soil rut produced from tracked vehicle operation was determined at various driving modes (straight, smooth turn, sharp turn). The width and depth of track rut and height of soil piled increased when the tracked vehicle negotiated a sharp turn. The results of this study indicate for the soil conditions tested, the width of disturbance is dependent on the operating characteristics of the vehicle. A vehicle conducting sharp turns will disturb a larger width of soil than a vehicle traveling straight or conducting smooth turns.

2. Cully, J.F. and S.L. Winter, "Evaluation of Land Condition Trend Analysis for Birds on a Kansas Military Training Site," *Environmental Management*, vol 25, no. 6 (2000), pp 625-633.

Land condition trend analysis (LCTA) is a long-term monitoring program used on military training lands to identify ecological changes that result from training and management activities. We initiated LCTA at the Kansas Army National Guard Training Facility (KANGTF) in Saline County, Kansas, in March 1998. This paper evaluates the LCTA methodology for birds by comparing LCTA results with a modified methodology designed to place sampling transects in field-identified rather than satellite-identified land-cover types. In the satellite-identified land-cover types developed at the site, grassland habitats included a large component of woody vegetation, which resulted in poor resolution of bird assemblages associated with the different land-cover types. Using these cover classes, mixed grass prairie included five grass/forb (g/f) and 10 woody-dependent species; old-field included four g/f and four woody-dependent species; and riparian included one g/f and six woody-dependent species. LCTA sampling

was too limited in the ecologically important riparian woodland habitat with the result that bird species were not adequately sampled there. In the alternate sampling strategy, we identified three land-cover classes (grassland, hedgerow, and riparian woodland) by field reconnaissance and increased sampling in the riparian woodland. Grassland included six g/f and three woody-dependent species; hedgerow included six g/f and 20 woody-dependent species, and riparian included two g/f and 19 woody-dependent species. The modifications greatly improved the resolution of bird assemblages associated with land-cover classes at the KANGTF. Use of the alternative sampling method should improve the ability to detect long-term trends in the bird communities.

3. Diersing, V.E. and W.D. Severinghaus, *The Effects of Tactical Vehicle Training on the Lands of Fort Carson, Colorado - An Ecological Assessment*, Technical Report N-85/03, U.S. Army Construction Engineering Research Laboratory (CERL), (1984).

Extensive field studies were conducted at Fort Carson, CO, to quantify the effects of Army tracked vehicle training on mammals, birds, vegetation, and soils. Ecological variation between two major habitats — pinyon-juniper woodland and shortgrass prairie — was quantified. Soil disaggregation and increased bulk density resulting from training activities were observed on both habitats. On the pinyon-juniper site, trees and shrub cover decreased, herbaceous cover increased, open-field and edge bird guilds increased, and the woodland bird guilds decreased. On the shortgrass prairie site, perennial grass cover decreased, weedy forb production increased, and open-field bird guilds decrease. On both sites, mammals favoring weedy habitats increased.

4. Diersing, V.E. and W.D. Severinghaus, *Wildlife as an Indicator of Site Quality and Site Trafficability During Army Training Maneuvers*, Technical Report N-86/03, U.S. Army Construction Engineering Research Laboratory (CERL), (1985).

Field studies were conducted on four prairies during May-June 1983 on the Pinon Canyon Maneuver Site and Fort Carson Colorado, to characterize the relationship of soils and vegetation to bird and mammal species composition and abundance. Results strongly suggest that meadowlark numbers increase and horned larks decrease with increasing grass cover, and that kangaroo rats increase and pocket mice decrease with increasing soil sand. Estimating the numbers of each species on various sites on semiarid maneuver lands may be an effective management tool for installation land management. The data can be used to assess the erodability (relative grass cover) and trafficability (soil texture) of various shortgrass prairie sites.

5. Goran, W.D., L.L. Radke, and W.D. Severinghaus, *An Overview of the Ecological Effects of Tracked Vehicles on Major U.S. Army Installations*, Technical Report N-142, U.S. Army Construction Engineering Research Laboratory (CERL), (1983).

Various levels of field studies were done on 12 U.S. Army Training and Doctrine Command (TRADOC) and U.S. Army Forces Command (FORSCOM) installations to provide a general overview of ecological disturbance caused by U.S. Army tactical vehicle training. Detailed quantitative data were obtained from Forts Polk, Knox, Hood, and Lewis; supplementary semi-quantitative and qualitative studies were done at Forts Benning, Bliss, Carson, Drum, Irwin, Riley, and Stewart, and at Yakima Firing Range. The overall results varied, depending on the installation and ecosystem studied. The following results were obtained:

- Mammal populations show a change in species composition, with increases in white-footed mice and decreases in shrews, wood rats, voles, moles, squirrels, and chipmunks. Heteromyid rodents (kangaroo mice and rats) remain virtually unchanged. Biomass reductions sometimes occur, depending on the species composition of the original population. On some severely impacted sites, populations of all species are reduced.
- Bird populations generally show significant biomass reduction. The concurrent change in diversity is not wholly evident, since numbers of species remain about the same. The important change is in species replacement. In most training areas and ecosystems, species which are secretive or highly sensitive to disturbance are replaced by less sensitive species; many of these are clearly disturbed site, early successional, or introduced species.
- Plant populations are drastically reduced and altered due mainly to: loss during clearing/preparation operations; physical contact with training vehicles, which either kills the plant or causes injury great enough to kill it; and root damage, reduced seed germination, or reduced seedling growth due to soil compaction. Climax species tend to be replaced by early successional species, and, to varying degrees, by a reversal of the successional process.
- Soil problems are universal due to increased erosion caused by compaction of the lower horizons, loosening of the upper horizons, and removal of vegetative cover. The extent of these problems varies, depending on factors such as slope, soil type, depth to bedrock, rainfall, and vegetative cover.

6. Hirst, R.A., R.F. Pywell, and P.D. Putwain, "Assessing Habitat Disturbance Using an Historical Perspective: The Case of Salisbury Plain Military Training Area," *Journal of Environmental Management*, vol 60, no. 2 (2000), pp 181-193.

Chalk grasslands are a habitat with high European importance for both flora and fauna. The largest known expanse of unimproved chalk grassland in northwest Europe lies within the Salisbury Plain training area (SPTA) in SW England, where sole use of the land for military training since the end of the nineteenth century has limited the ecologically damaging impacts of modern intensive agriculture. Organizational changes in the British Army may now paradoxically be threatening this unique ecological resource. In this study, historical aerial photograph analysis was carried out for SPTA using images from the 1940s through to the mid 1990s. Image analysis software enabled the creation of a model that analyzed the extent and pattern of high intensity military disturbance on SPTA at a local landscape scale. Although trends in disturbance vary across SPTA for the time period under investigation, the average annual increase in bare ground since WWII has been in the region of 25.5ha. These trends indicate that disturbance is occurring at a greater rate than natural regeneration, representing a significant threat to the chalk grassland through habitat loss and fragmentation.

7. Johnson, F.L., "Effects of Tank Training Activities on Botanical Features at Fort Hood, Texas," *The Southwestern Naturalist*, vol 27, no. 3 (8-20-1982), pp 309-314.

Two sites, one relatively undisturbed and one heavily used for training activities, were sampled in the upland *Juniperus ashei-Quercus fusiformis* community. Effects of intensive tank training over a period of years are: (1) reduction of total plant cover by approximately 60%; (2) disturbance and consequent erosion of about 60% of the soil surface; (3) reduction in density and cover of woody vegetation without any major change in species composition; and (4) a major shift in herbaceous plant species from perennials to small annuals. Continued use of the same site for training will probably not result in much further deterioration.

8. Knick, S.T. and J.T. Rotenberry, "Landscape Characteristics of Disturbed Shrubsteppe Habitats in Southwestern Idaho (USA),"*Landscape Ecology*, vol 12, no. 5 (1997), pp 287-297.

We compared five zones in shrub-steppe habitats of southwestern Idaho to determine the effect of differing disturbance combinations on landscapes that once shared historically similar disturbance regimes. The primary consequence of agriculture, wildfires, and extensive fires ignited by the military during training

activities was loss of native shrubs from the landscape. Agriculture created large square blocks on the landscape, and the landscape contained fewer small patches and more large shrub patches than non-agricultural areas. In contrast, fires left a more fragmented landscape. Repeated fires did not change the distribution of patch sizes, but decreased the total area of remaining shrublands and increased the distance between remaining shrub patches that provide seed sources. Military training with tracked vehicles was associated with a landscape characterized by small, closely spaced, shrub patches. Our results support the general model hypothesized for conversion of shrublands to annual grasslands by disturbance. Larger shrub patches in the region, historically resistant to fire spread and large-scale fires because of a perennial bunchgrass understory, were more fragmented than small patches. Presence of cheatgrass (*Bromus tectorum*), an exotic annual, was positively related to landscape patchiness and negatively related to number of shrub cells. Thus, cheatgrass dominance can contribute to further fragmentation and loss of the shrub patch by facilitating spread of subsequent fires, carried by continuous fuels, through the patch. The synergistic processes of fragmentation of shrub patches by disturbance, invasion and subsequent dominance by exotic annuals, and fire are converting shrubsteppe in southwestern Idaho to a new state dominated by exotic annual grasslands and high fire frequencies.

9. Krzysik, A.J., *Biodiversity and the Threatened / Endangered / Sensitive Species of Fort Irwin, CA,* Technical Report EN-94/07, U.S. Army Construction Engineering Research Laboratory (CERL), (1994).

Properly designed and implemented inventory, assessment, and monitoring programs are important components of environmental compliance for U.S. Army training installations. In earlier work, a statistically rigorous and quantitative assessment and monitoring program for arid and semiarid ecosystems was developed and initialed for the Mojave Desert. The program was implemented in March 1983 at Fort Irwin, CA, the Army's National Training Center (NTC), to monitor woody perennial vegetation and vertebrate populations. Data from that program, and ongoing work by the author, have produced analytical capabilities to quantitatively assess the effects of training activities on ecosystems at landscape scales. Such assessments are needed to determine environmental mitigation and management priorities, and future monitoring and research priorities. This report describes the biological and geophysical characteristics and environment of Fort Irwin, describes the Army training mission at the NTC, and summarizes the effects of the military training mission at Fort Irwin on woody vegetation and the vertebrate fauna. A detailed assessment of the current status of threatened, endangered, and sensitive animals and plants is also given. Priori-

ties for environmental management, mitigation, research, and monitoring at Fort Irwin — based on sound ecological principles and the authors cumulative research in the Mojave Desert ecosystem — are discussed.

10. Lathrop, E.W., "Recovery of perennial vegetation in military maneuver areas." In: Webb, R.H. and H.G. Wilshire (eds.) *Environmental effects of off-road vehicles: impacts and management in arid regions*, (1983), pp 265-277.

The California deserts have been used for many years as training grounds for the U.S. military. In addition to full-scale training exercises, ongoing military impacts arise from the active military bases at Fort Irwin, Twenty-nine Palms, China Lake, and the Chocolate Mountains in California. Two sites of General Patton's World War II training areas were studied to survey the impacts of armored maneuvers on perennial vegetation of the eastern Mojave Desert, California. The data on heavily concentrated use between 1938 and 1942 can be useful for determining recovery rates of vegetation and predicting the longevity of disturbances created by off-road vehicle use. Two time periods were studied to assess recovery. First, aerial photographs were analyzed to determine recovery between 1953 and 1974. The second phase of the study was an on-site ground analysis of differences between the disturbed and control (undisturbed) sites to detect the extent of recovery from the original disturbance over a period of approximately 36 years. The impacts were assessed in three categories: (1) tank areas, (2) tent areas, (3) roadways. Measurements of the ground transects were made using the point-quarter method in approximately the same locations as the aerial photographic analysis to assess differences/similarities between tank tracks, tent areas, and roadways and their respective controls. Concentrated use at the study sites has resulted in significant reduction in vegetation densities and covers, despite the long period of time for recovery. Differences in percentage composition indicates alteration of both plant stability and diversity.

11. Lehman, R.N., K. Steenhof, M.N. Kochert, and L.B. Carpenter, "Effects of Military Training Activities on Shrub-steppe Raptors in Southwestern Idaho, USA," *Environmental Management*, vol 23, no. 3 (1999), pp 409-417.

Between 1991 and 1994, we assessed relative abundance, nesting success, and distribution of ferruginous hawks (*Buteo regalis*), northern harriers (*Circus cyaneus*), burrowing owls (*Athene cunicularia*), and short-eared owls (*Asio flammeus*) inside and outside a military training site in the Snake River Birds of Prey National Conservation Area, southwestern Idaho. The Orchard Training Area is used primarily for armored vehicle training and artillery firing by the Idaho Army National Guard. Relative abundance of nesting pairs inside and outside the training site was not significantly different from 1991 to 1993 but was significantly higher on the training site in 1994 ($P \leq 0.03$). Nesting success

varied among years but was not significantly different inside and outside the training site ($P > 0.26$). In 1994, short-eared owl and burrowing owl nests were significantly closer to firing ranges used early in the spring before owls laid eggs than were random points ($P < 0.001$). In 1993, distances from occupied burrowing owl nests to firing ranges used early in the year were similar to those from random points to the same firing ranges ($P = 0.16$). Military activity contributed to some nesting failures from 1992 to 1994, but some pairs nested successfully near military activity

12. Lovich, J.E. and D. Bainbridge, "Anthropogenic Degradation of the Southern California Desert Ecosystem and Prospects for Natural Recovery and Restoration," *Environmental Management*, vol 24, no. 3 (1999), pp 309-326.

Large areas of the southern California desert ecosystem have been negatively affected by off-highway vehicle use, overgrazing by domestic livestock, agriculture, urbanization, construction of roads and utility corridors, air pollution, military training exercises, and other activities. Secondary contributions to degradation include the proliferation of exotic plant species and a higher frequency of anthropogenic fire. Effects of these impacts include alteration or destruction of macro- and micro-vegetation elements, establishment of annual plant communities dominated by exotic species, destruction of soil stabilizers, soil compaction, and increased erosion. Published estimates of recovery time are based on return to predisturbance levels of biomass, cover, and density, community structure, or soil characteristics. Natural recovery rates depend on the nature and severity of the impact but are generally very slow. Recovery to predisturbance plant cover and biomass may take 50-300 years, while complete ecosystem recovery may require over 3000 years. Restorative intervention can be used to enhance the success and rate of recovery, but the costs are high and the probability for long-term success is low to moderate. Given the sensitivity of desert habitats to disturbance and the slow rate of natural recovery, the best management option is to limit the extent and intensity of impacts as much as possible.

13. Michaels, H.L. and J.F. Cully, "Landscape and Fine Scale Habitat Associations of the Loggerhead Shrike," *Wilson Bulletin*, vol 110, no. 4 (1998), pp 474-482.

This study was conducted to determine landscape and fine-scale vegetative variables associated with breeding Loggerhead Shrikes (*Lanius ludovicianus*) on Fort Riley Military Reservation, Kansas. Because Fort Riley is an Army training site, the influences of training disturbance to the vegetation, and range management practices on bird habitat patterns were also investigated. Breeding birds were surveyed in 1995 and 1996 using point counts. Survey plots were

identified, a priori, at the landscape scale as either grassland, savannah, or woodland edge according to cover by woody vegetation. In 1996, fine-scale habitat at survey points and at bird use sites was measured and a principal components analysis used to characterize the fine-scale herbaceous vegetation structure. A military disturbance index was developed to quantify the severity of vehicle disturbance to the vegetation at survey and bird use sites. Shrikes were associated with savannah habitat at the landscape scale. Sites used by Loggerhead Shrikes were characterized at the fine scale by tall, sparse, structurally heterogeneous herbaceous vegetation with high standing dead plant cover and low litter cover. At the fine scale, tree and shrub density did not differ between sites used and not used by shrikes. Used sites did not differ from survey sites with respect to military training disturbance, hay harvest, or the number of years since a site was last burned. Results in this study suggest that the shifting mosaic of vegetation on Fort Riley resulting from training and range management practices maintains adequate habitat for breeding shrikes.

14. Milchunas, D.G., K.A. Schulz, and R.B. Shaw, "Plant Community Responses to Disturbance by Mechanized Military Maneuvers," *Journal of Environmental Quality*, vol 28, no. 5 (1999), pp 1533-1547.

The effects of 10 years of military training exercises on vegetation structure were assessed across plant communities that differed in physiognomy and soil texture at Pinon Canyon Maneuver Site (PCMS), Colorado, after release from previous grazing management. Covariate analyses aided in separating temporal trends due to both release from grazing and imposition of training disturbance from the direct effect of training. The shift in land use had both synergistic and antagonistic impacts on successional trajectories of communities, and on horizontal and vertical structural heterogeneity. Vegetation basal cover declined with increasing intensity of disturbance by tracked vehicles, but release from grazing acts additively in this ecosystem. Litter cover increased following release from grazing, even though it declined with increasing levels of disturbance. Vehicular maneuvering generally reduced woody life forms in tall-height classes to a greater extent than short-height classes. Low-growing cacti were susceptible to crushing. Species and functional group responses to vehicular disturbance were sometimes dependent on community type. Long-lived perennials declined, but were replaced by short-lived perennials in only the shrub-grassland community. Annuals and exotics did not show relationships with intensity of disturbance, though some weed species increased. Community-wide species dissimilarity did not show large shifts, and patterns in species diversity or richness were not related to intensity of disturbance. The PCMS appears to be in a transient stage where release from grazing has had as much or more impacts as did the imposi-

tion of military training. Fine textured soils may be more susceptible to the cumulative effects of vehicular loads.

15. Milchunas, D.G., K.A. Schulz, and R.B. Shaw, "Plant Community Structure in Relation to Long-term Disturbance by Mechanized Military Maneuvers in a Semiarid Region," *Environmental Management*, vol 25, no. 5 (2000), pp 525-539.

Mechanized military maneuvers are an intensive form of disturbance to plant communities in large areas throughout the world. Tracking by heavy vehicles can cause direct mortality and indirectly affect plant communities through soil compaction and by altering competitive relationships. We assessed the long-term condition of structural attributes of open woodland, grassland, and shrubland communities at Fort Carson, Colorado, in relation to levels of disturbance and soil texture. Covariate analyses were used to help separate the directional forcings by the chronic disturbance from the regenerative capacities in order to assess the relative resistance and resilience of the communities and to determine whether the continual disturbance-recovery processes balanced under current levels of utilization. All three communities responded differently to disturbance. In open woodlands, altered understory/overstory relationships were suggested by increased grass, forb, shrub, and total vegetation cover and smaller decreases in shorter than taller woody species with increasing levels of disturbance. Grassland communities generally displayed greater responses to disturbance than other communities, but temporal dynamics were often similar, indicating relatively less resistance but greater resilience of this community. Weed and exotic species increased both temporally and in relation to levels of disturbance in all three community types. Temporal trends in community-level indices of dissimilarity and diversity also indicate that rates of disturbance were greater than rates of recovery. Few variables were related to within-community differences in soil texture. While total aerial cover was temporally stable, changes in species composition and in basal cover in grasslands and shrublands suggest increasing erosion potential.

16. Minor, T.B., J. Lancaster, T.G. Wade, J.D. Wickham, W. Whitford, and K.B. Jones, "Evaluating change in rangeland condition using multitemporal AVHRR data and geographic information system analysis," *Environmental Monitoring And Assessment,* vol 59, no. 2 (1999), pp 211-223.

Coarse-scale, multi-temporal satellite image data were evaluated as a tool for detecting variation in vegetation productivity, as a potential indicator of change in rangeland condition in the western United States. The conterminous United States Advanced Very High Resolution Radiometer (AVHRR) biweekly composite

data set was employed using the six-year time series 1989-1994. Normalized Difference Vegetation Index (NDVI) image bands for the state of New Mexico were imported into a Geographic Information System (GIS) for analysis with other spatial data sets. Averaged NDVI was calculated for each year, and a series of regression analyses were performed using one year as the baseline. Residuals from the regression line indicated 14 significant areas of NDVI change: two with lower NDVI, and 11 with higher NDVI. Rangeland management changes, cross-country military training activities, and increases in irrigated cropland were among the identified causes of change.

17. Prose, D.V., "Persisting Effects of Armored Military Maneuvers on Some Soil of the Mojave Desert," *Environmental Geology and Water Sciences*, vol 7, no. 3 (1985), pp 163-170.

Soil compaction and substrate modification produced during large-scale armored military maneuvers in the early 1940's were examined in 1981 at seven sites in California's eastern Mojave Desert. Recording penetrometer measurements show that tracks left by a single pass of an M3 "medium" tank have average soil resistance values that are 50% greater than those of the surrounding untracked soil in the upper 20 cm. At one site, measurements made along short segments of track that have been visually eliminated by erosion and deposition processes show a 73% increase in penetrometer resistance over adjacent, undisturbed soil. Dirt roadways at three former base camp locations could not be penetrated below 5-10 cm because of extreme compaction. Soil bulk density was not as sensitive an indicator of soil compaction as was penetrometer resistance. Density values in the upper 10 cm of soil are not significantly different between tank tracks and undisturbed soils at most sites, and roadways at two base camps show an average increase in bulk density of only 12% over adjacent soils. Trench excavations across tank tracks show that physical modifications of the substrate can extend vertically beneath a track to a depth of 25 cm and outward from a track's edge to 50 cm. These soil disturbances are probably major factors that encourage accelerated soil erosion throughout the maneuver area and also retard or prevent the return of vegetation to pre-disturbance conditions.

18. Prosser, C.W., K.K. Sedivec, and W.T. Barker, "Tracked Vehicle Effects on Vegetation and Soil Characteristics," *Journal of Range Management*, vol 53, no. 6 (2000), pp 666-670.

A 3-year experiment to evaluate tracked vehicle effects on vegetation and soil characteristics was established on the Gilbert C. Grafton South State Military Reservation (CGS) in North Dakota. Study objectives were to evaluate the ef-

fects of 3 tracked vehicle use intensity treatments on plant species cover and frequency, and soil compaction. The 3 treatments evaluated include heavy use (74 passes), moderate use (37 passes) and no use. The moderate use treatment represents a typical use of 1 battalion unit at CGS with the heavy use treatment classified as 2 battalion units. This land area comprised a 50 by 150 meter block subdivided into three, 50 by 50 meter blocks. Each 50 by 50 meter block was subdivided into three, 16.7 by 50 meter blocks with each block treated with 1 of the 3 treatments. Soil bulk density increased ($P < 0.05$) on the moderate and heavy use treatments in the 0 to 15, 30 to 45, and 45 to 60 cm soil depths. Kentucky bluegrass (*Poa pratensis* L.) cover ($P < 0.05$) decreased in 1996 on both the moderate and heavy use treatments but was not ($P > 0.05$) different among all treatments in 1997. The tracked vehicle use on the heavy and moderate treatments did not change species composition or litter amounts after 2 years; however, bulk density and bare ground increased on both treatments in 1996 and 1997.

19. Severinghaus, W.D., W.D. Goran, G.D. Schnell, and F.L. Johnson, *Effects of Tactical Vehicle Activity on the Mammals, Birds, and Vegetation at Fort Hood Texas*, Technical Report N-113, U.S. Army Construction Engineering Research Laboratory (CERL), (1981).

A field study was conducted at Fort Hood, TX, to investigate the effects of Army tracked vehicle training on the resident mammal, bird, and plant populations. This report: (1) describes preliminary indications of ecological differences between selected areas used for vehicle training and areas undisturbed by training, (2) documents the procedures used to obtain this information, and (3) analyzes Fort Hood's ecosystem to verify the effects of training activities on ecosystems examined in previous research.

20. Severinghaus, W.D. and W.D. Goran, *Effects of Tactical Vehicle Activity on the Mammals, Birds, and Vegetation at Fort Lewis, Washington*, Technical Report N-116, U.S. Army Construction Engineering Research Laboratory (CERL), (1981).

A field study was conducted at Fort Lewis, WA, to investigate the effects of Army tracked vehicle training on the resident mammal, bird, and plant populations. This report: (1) describes preliminary indications of ecological differences between selected areas used for vehicle training and areas undisturbed by training, (2) documents the procedures used to obtain this information, and (3) analyzes Fort Lewis' ecosystem to verify the effects of training activities on ecosystems examined in previous research.

21. Severinghaus, W.D., R.E. Riggins, and W.D. Goran, *Effects of Tracked Vehicle Activity on Terrestrial Mammals, Birds, and Vegetation at Fort Knox, KY*, Special Report N-77, U.S. Army Construction Engineering Research Laboratory (CERL), (1979).

A field study was conducted at Fort Knox, KY, to investigate the effects of Amy tracked vehicle training on terrestrial birds, mammals, and vegetation. Intensive studies were conducted at three sites representative of a long-tern training area, a short-term training area, and a control area. This report describes the survey procedures used and provides preliminary indications of ecological differences between Amy tracked vehicle training areas and areas representing pre-training (no training) conditions.

22. Shaw, R.B. and V.E. Diersing, "Evaluation of the Effects of Military Training on Vegetation in Southeastern Colorado," *Headwaters Hydrology* (1989), pp 223-231.

This study assessed impacts of tracked vehicular training on the grassland, shrubland, and woodland vegetation at the Pinon Canyon Maneuver Site (PCMS) located in southeastern Colorado. Live and litter basal cover decreased and bare ground increased in tracked areas in 1986 and 1987 following training. Species composition shifted from perennial warm-season grasses to annual cool-season grasses and annual warm-season forbs in the tracked areas. Shrubby and woody plant densities were significantly reduced by training. Extended rest and/or land restoration and improvement practices are warranted to return disturbed areas to perennial cover prior to additional use on deferred training areas.

23. Shaw, R.B. and V.E. Diersing, "Tracked Vehicle Impacts On Vegetation at the Pinon Canyon maneuver Site, Colorado, USA," *Journal of Environmental Quality*, vol 19, no. 2 (1990), pp 234-243.

The effects of military tracked vehicle maneuvers on the vegetation of the Pinon Canyon Maneuver Site (PCMS), southeastern Colorado, were assessed from 1985 to 1987. Tracking decreased plant basal and litter cover and increased bare ground. The immediate effect of tracked vehicles was to reduce perennial warm-season grasses [primarily blue grama, *Bouteloua gacilis* (H.B.K.) Lag. ex. Griffith] followed by the invasion of annual cool-season grasses [sixweeks grass, *Vulpina octoflora* (Walt.) Tybd., and little barley, *Hordeum pusillum* Nutt.] and annual warm-season forbs [sunflower, *Helianthus annuus* L., Russian thistle, *Salsola iberica* Sennen & Pau, and kochia, *Kochia scoparia* (L.) Schrab.]. In untracked areas, herbaceous plant composition did not change: however, litter in-

creased and bare ground and basal cover decreased. Changes in cover in untracked areas was attributed to above average precipitation and the cessation of domestic livestock grazing. Overall (tracked plus untracked area), total cover increased on PCMS, but the proportion of annual cover also increased. Woody plant density decreased an average of 9% from 1985 to 1987. Long-term management of the soil and vegetation resources of PCMS are discussed.

24. Thurow, T.L., S.D. Warren, and D.H. Carlson, "Tracked Vehicle Traffic Effects on the Hydrologic Characteristics of Central Texas Rangeland," *Transactions of the ASAE*, vol 36, no. 6 (1993), pp 1645-1650.

The initial change and the temporal recovery pattern of hydrologic, soil, and vegetation characteristics following tracked vehicle passage (tracking) were documented in a split-plot experiment. Treatments were characterized by different soil moisture conditions at the time of vehicle passage (wet or dry) and different tracking intensities (0, 1, 4, and 10 passes by a M2 Bradley Infantry Fighting Vehicle). The study was conducted at Fort Hood, located in the Cross-Timber Prairie ecological resource zone of Texas. Dry-tracked (tracking disturbance imposed on dry soil) plots did not have significantly different infiltration rates or interrill erosion than control plots at any time during the study. In contrast, wet-tracked (tracking disturbance imposed on wet soil) plots had significantly lower infiltration and significantly greater interrill erosion rates, with the initial response and the period of recovery being greater as the number of vehicle passes increased. Bulk density in the top 50 mm was the variable most strongly correlated with infiltration rate immediately following the vehicle traffic. This correlation decreased with passage of recovery time and the strongest predictive factor became the percent exposed soil. This change can be attributed to the natural amelioration (e.g., clay expansion and contraction associated with wetting and drying, activity of soil biota) of soil structure and the death and decomposition of bunchgrasses in the tracks, which were replaced, by annual grasses and forbs that provided less cover. After two years the soil structure, vegetation cover, and standing crop had recovered to the point that there was no longer any significant difference between treatments in their collective influence on infiltration rate or interrill erosion.

25. Trame, A. *Known and Potential Impacts of Physical Disturbance from Maneuver Training on Threatened and Endangered Species*, Technical Note 97/70, U.S. Army Construction Engineering Research Laboratory (1997).

Natural habitat remains intact and rare species exist to a remarkable extent on military installations, even in the presence of military training. However, there

has been little field research directed at identifying and quantifying possible impacts to threatened and endangered species (TES) from disturbances related to training activities. This research describes known impacts to TES resulting from military training, describes potential impacts to TES by reporting impacts from similar activities such as recreational use, and generally identifies gaps in current knowledge about the impact of military training on TES to encourage future research. This research serves as an introduction to the ecological processes that can lead to impacts on sensitive species. An increased information base about how impacts can occur will assist trainers in decision making and planning to mitigate impacts and encourage communication between the natural resources community and the training community at Major Army Commands and installations.

26. Trame, A. and M. Harper. *Potential Military Effects on Selected Plant Communities in the Southeastern United States.* Technical Report 97/115, U.S. Army Construction Engineering Research Laboratory (CERL), (1997).

Military training and testing mission requirements make up the highest priority land uses on Department of Defense (DoD) lands. The U.S. Armed Forces require realistic, relatively natural, and expansive areas for adequate training. Training activities can lead to degradation of sensitive natural resources but they also produce benefits. An ecosystem-based approach to managing threatened, endangered, and sensitive species (TES) and other natural resources provides DoD with an efficient, effective, and flexible framework for evaluating impacts, assessing natural resources, and generating management solutions to potential conflicts between training and TES conservation. Any increase in understanding about the habitat requirements of listed TES species will assist training and natural resources personnel in complying with the Endangered Species Act while avoiding restrictions on the military mission. This report is to be used by DoD land managers, policymakers, installation land managers, and the natural resource research community, in conjunction with associated documents produced by this SERDP work unit to (1) develop ecosystem-based approaches to describe natural communities and TES habitat in relation to military activities, (2) evaluate military-related effects on those communities, (3) develop community-based strategies for supporting both military land use and TES habitat management, and (4) develop management solutions for military impacts to natural communities when management for TES habitat is a priority for a particular location.

27. Tweddale, Scott A. *Historical Analysis of Land Cover / Condition Trends at Fort Bliss, Texas, Using Remotely Sensed Imagery*, Engineer Research and Development Center/Construction Engineering Research Laboratory (ERDC/CERL) TR-01-36 (April 2001).

Fort Bliss, Texas, is a Training and Doctrine Command (TRADOC) installation located in the semi-arid Northern Chihuahuan Desert of Western Texas and South Central New Mexico. Military training (both tracked and wheeled vehicles), grazing, and recreational activities act as stressors on the landscape. The natural resource managers need information on land condition to make informed land management decisions and to support conservation and compliance efforts. They need a cost-effective method of assessing and monitoring land condition.

The objective of this research was to characterize the small-scale, gross level change in land condition on a selected area of Fort Bliss over a 23-year period. The evaluation and analysis was based on several vegetation and brightness indices calculated from temporal, archival multispectral imagery.

Trends in brightness and greenness indices varied considerably. Most variation could be due to natural differences in the amount of precipitation in the region. There was no indication of permanent, long-term changes in the land condition. The study area appeared to be resilient, with no clearly observable trends in either long-term degradation or improvement. The brightness and greenness indices calculated from temporal image data sets provides a cost-effective method for monitoring relative trends in land condition.

28. Tweddale, Scott A., Verl Emrick, and William Jackson. *Integrating Remote Sensing and Field Data to Monitor Changes in Vegetative Cover on a Multipurpose Range Complex and Adjacent Training Lands at Camp Grayling, Michigan*, ERDC/CERL TR-01-45 (May 2001).

Vegetative cover was inventoried on a Multi-Purpose Range Complex (MPRC) and adjacent training area to Camp Grayling, MI. Camp Grayling is a U.S. Army National Guard installation located in the north central area of Michigan's lower peninsula. Remote sensing and field surveys were used to determine vegetative cover. In the field, vegetative cover data were collected on systematically allocated plots during the peak of the growing season in 1997. A Landsat Thematic Mapper (TM) image of the study area was acquired on 8 August 1997 that coincided with field data collection. A Transformed Normalized Difference Vegetation Index (TNDVI) image was derived from spectral information contained within the TM image. Analysis of correlation of vegetative cover measurements

from field surveys and TNDVI values derived from satellite imagery were performed. Strong correlations between TNDVI values and several in situ vegetative cover measurements were identified, including Organic Cover (R^2 = 69.1), Visible Bare Ground (R^2 = 65.6), Total Cover (R^2 = 77.6), Total Vegetative and Organic Cover (R^2 = 79.2), and Total Vegetative Cover (R^2 = 70.4). Correlations were stronger within the MPRC than the adjacent training area (R^2 for Total Vegetative Cover; MPRC = 70.4, Adjacent Training Area = 53.5). Based upon these correlations, spatially explicit vegetative cover estimates were extrapolated across the two training areas. The resulting estimates provided a baseline survey of vegetative cover from which spatial and temporal changes in vegetation cover can be monitored.

29. Van Horne, B. and P.B. Sharpe, "Effects of Tracking by Armored Vehicles on Townsend's Ground Squirrels in the Orchard Training Area, Idaho, USA," *Environmental Management*, vol 22, no. 4 (1998), pp 617-623.

Maintaining raptor populations is a primary objective of the legislation that designates the Snake River Birds of Prey National Conservation Area. Army training activities could influence habitat quality for raptors by changing the density, productivity, or behavior of their Townsend's ground squirrel (*Spermophilus townsendii*) prey. These changes could occur directly or as a result of changes in the vegetation available as food and cover for the ground squirrels. We assessed the effects of long-term tracking by armored vehicles by comparing 9-ha areas in sagebrush (*Artemisia tridentata*)-dominated shrubsteppe and bluegrass (*Poa secunda*)-dominated grasslands subjected to low-intensity tracking for 50 years with others that had not been tracked. We did not detect any effect on ground squirrel population dynamics associated with long-term tracking. Although densities of adults and juveniles tended to be higher in the areas exposed to such tracking, we attribute this difference to other factors that varied spatially. To determine short-term (two-year) effects, we experimentally tracked two sagebrush and two grassland sites with an M-1 tank after animals had begun their inactive season. In the following two active seasons we monitored squirrel demography and behavior and vegetative characteristics on the experimentally tracked sites and compared the results with control sites. Although we experimentally tracked similar to 33% of the surface of each of four sites where ground squirrel densities were assessed, the tracking had a detectable effect only on some herbaceous perennials and did not influence ground squirrel densities or behavior significantly during the subsequent two active seasons. We conclude that tracking after the start of the inactive season is likely to influence ground

squirrel demography or behavior only if vegetation cover is substantially changed by decreasing coverage of preferred food plants or increasing the coverage of annual grasses and forbs that are succulent for only a short time each year.

30. Vertegaal, P.J.M., "Environmental Impacts of Dutch Military Activities," *Environmental Conservation*, vol 16, no. 1 (1989), pp 54-64.

Much has been said and written in the past two decades about the world-wide problem of maintaining an unharmed environment for Man and Nature. However, the military sector has been has been rather neglected in this respect. Protests by the environmental movement in The Netherlands has forced the Ministry of Defence to investigate the effects of military exercises on soil, vegetation, and fauna. This document discusses the Dutch military's consumption of energy and raw materials, and the resulting hazardous wastes including beryllium, depleted uranium, plutonium, CFCs, acids, and heavy metals. It includes a brief explanation of the military land use for training, and military noise pollution. The author lists the most important results of various environmental research projects: (1) driving with tracked and wheeled vehicles has led to serious loss of vegetation and to soil compression, which has caused flooding and erosion, (2) direct effects of driving can still be detected after 25 years, (3) the area of irreparable damage has increased to 25% of the 9,000 ha of training grounds and is predicted to increase to 70%, (4) diversity of birds and mammals is decreasing, (5) rare, migratory birds are being disrupted, and (6) negative effects of noise experiments can probably be documented only after it is too late, after the new shooting ranges come into use. The Dutch military is also involved in large training exercises in the Federal Republic of Germany, France, and Canada, with similar negative impacts. Acknowledging that the future of military training will probably intensify, the author recommends more research into environmental impacts of military activities, and the preparation of Environmental Impact Studies.

31. Watts, S.E., "Short-term Influence of Tank Tracks on Vegetation and Microphytic Crusts in Shrubsteppe Habitat," *Environmental Management*, vol 22, no. 4 (1998), pp 611-616.

I examined vegetation and microphytic crust cover on two sites in burned and two sites in unburned big sagebrush (*Artemisia tridentata* Nutt.) habitat within the Idaho Army National Guard Orchard Training Area in southwestern Idaho. The purpose of this study was to determine the short-term (1-2 years) influence of tank tracks on vegetation and microphytic crusts in shrubsteppe habitat. The

two types of tank tracks studied were divots (area where one track has been stopped or slowed to make a sharp turn) and straight-line tracks. Divots generally had a stronger influence on vegetation and microphytic crusts than did straight-line tracks. Tank tracks increased cover of bare ground, litter, and exotic annuals, and reduced cover of vegetation, perennial native grasses, sagebrush, and microphytic crusts. Increased bare ground and reduced cover of vegetation and microphytic crusts caused by tank tracks increase the potential for soil erosion and may reduce ecosystem productivity. Reduced sagebrush cover caused by tank tracks may reduce habitat quality for rodents. Tank tracks may also facilitate the invasion of exotic annuals into sagebrush habitat, increasing the potential for wildfire and subsequent habitat degradation. Thus, creation of divots and movement through sagebrush habitat by tanks should be minimized.

32. Wilson, S.D., "The Effects of Military Tank Traffic on Prairie: A Management Model," *Environmental Management*, vol 12, no. 3 (1988), pp 397-403.

The effect of various frequencies and seasons of military tank traffic on native mixed-grass prairie was examined in a randomized replicated field experiment. Vegetation (in 10 x 10 m plots) was subjected to tank traffic at the following rates: (a) one pass per day of training from May until August; (b) one pass per day in May and June; (c) one pass per day in July and August; (d) one pass every three weeks from May until August; (e) zero (control). Species composition and the amount of bare ground were found to vary significantly with traffic frequency. Plant species alien to North America invaded plots subjected to spring driving. Regression analysis showed spring driving to produce more bare ground than summer driving. The regression models suggested that much higher intensities of training could be conducted without damage if spring driving were avoided. Regression models were also used to estimate the frequency of traffic associated with a significant change in species composition, where species composition was expressed as the ratio of *Boutelous gracilis* to *Stipa spartea*, an indicator of disturbance-induced change in prairie vegetation of a training area of any given width to support tank traffic without changing species composition. The predictive traffic capacities with the amount of traffic actually applied to two training areas in 1986. Where traffic capacity was exceeded, the model successfully predicted a significantly higher frequency of bare ground and ratio of *Bouteloua gracilis* to *Stipa spartea*.

5 Supporting Reference List

33. Balbach, H.E., *Military Land Management Research Tools: An Annotated Bibliography*, Special Report 96/65, U.S. Army Construction Engineering Research Laboratory (CERL), (1996).

Management of U.S. Army training lands is accomplished by two types of personnel, the active land manager, who is most focused on methods for identification and remediation of the environmental consequences of supporting the military testing and training mission, and the researcher who develops management tools and techniques to better assist the land manager. This bibliography is arranged so papers and reports believed most relevant to the active land manger are in one section of each topic area and those of more interest and value to the researcher are in a separate section. The bibliography covers 14 topic areas: (1) impacts of military training, (2) measurement and characterization of vegetation, (3) measurement and characterization of wildlife, (4) characterization of soils, erosion, and erosion protection, (5) land management principles, (6) the land condition trend analysis program, (7) training-related noise management, (8) characterization and management of threatened, endangered, and sensitive species, (9) survey and management of cultural resources, (10) assessment of environmental impacts for NEPA compliance, (11) environmental modeling in land management applications and related geographic information system technology, (12) environmental education and awareness, (13) land contamination as related to training and testing activities, and (14) management of fugitive dust.

34. Barret, P. and R. Schulten, "Disturbance and the Successional Response of Arctic Plants on Polar Desert Habitats," *Arctic*, vol 23 (1975), pp 70-73.

The concepts of succession and climax vegetation have proved to have considerable predictive value for ecologists. Numerous examples of the successional process have been described from temperate and boreal ecosystems. Early work in the arctic tundras of North America, however, generated questions about the validity of applying classical successional concepts in these regions. The lack of quantitative date on successional processes in the tundra remains acute, and knowledge of variation in community structure on a broad geographical basis remains fragmentary. These problems have taken on additional applied impor-

tance since attempts to establish restorative plant covers of non-arctic plant species are underway in the Canadian Arctic islands. This paper presents the results of observations of the successional response of three vascular plant species on polar desert microenvironments subjected to tracked vehicle disturbance. Values for total plant cover on the vehicle-disturbed area are, not unexpectedly, drastically reduced. More interestingly, however, are comparison of the three species in recolonization. *Saxifrage oppositifolia* seedlings yielded counts similar to those for undisturbed terrain. *Dryas integrifolia* populations remained severely reduced. *Minuartia rubella*, on the other hand, had substantially increased its numbers in comparison to undisturbed terrain. Further, in the majority of quadrats on the disturbed area, *Minuartia rubella* was now the major contributor to the total vascular cover. This study may provide valuable clues to the understanding of the successional process in tundra, but existing data are inadequate for long-range planning of land use.

35. Bliss, L.C. and R.W. Wein, "Plant Community Response to Disturbances in the Western Canadian Arctic," *Canadian Journal of Botany*, vol 50 (1972), pp 1097-1109.

Data are presented on several current studies being conducted in the Mackenzie Delta and the Arctic Archipelago in relation to oil and gas exploration. Tundra fires destroy most of the aboveground plant cover and result in significant increases in depth of the active layer. Fire simulated the growth and flowering of *Eriophorum vaginatum* subsp. *spissum* and *Calamagrostis canadensis*. The recovery of dwarf heath shrubs from rhizomes was relatively rapid while lichens and mosses showed no early recovery. Crude oil spilled in different plant communities killed the leaves of all species, yet regrowth occurred on some woody species the same summer and more species showed regrowth that second summer. Oil spilled in early winter (October) and in wet sedge communities in summer appeared to be most detrimental. Percentage plant removal has been significantly reduced with changed seismic technology in the past 6 years. Native species, often from rhizomes, reinvaded all lines though recovery on peats and by native grasses appears most rapid. Winter roads of compacted snow were less detrimental to wetland sedge communities than to upland dwarf shrub-sedge-heath ones. Upland sites, which were dry in summer, were more difficult to revegetate. The revegetation studies indicated that 100 kg/ha of elemental nitrogen and 200 kg/ha of phosphorus treatment was best and that early spring or late fall seeding was essential. About five perennial plus two annual grass species in varying mixtures grew best in the reseeding trials. The supply of available nitrogen appears to strongly limit plant growth of native species while phosphorus does not. Most of these nutrients are retained in the organic mat,

thus any disturbance that destroys this mat will seriously modify normal nutrient cycling and greatly increase the need for fertilizer in revegetation. In the High Arctic most soils are wet during snowmelt and thus subject to surface disturbance by vehicles. In the polar deserts, silty and sandy soils dry rather rapidly and show less evidence of disturbance later in summer. Lowland areas where there is a more complete cover of plants on wet shallow peat or silty soils are subject to rutting throughout the summer as in the Low Arctic. With surface disturbance there is much less thaw of the permafrost than occurs in the Delta. The different plant community-topographic-soil-ground ice landscape units or systems respond differentially to the different surface disturbances tested to date. This is true in both the Low and High Arctic.

36. Braunack, M.V., "The Residual Effects of Tracked Vehicles on Soil Surface Properties," *Journal of Terramechanics*, vol 23, no. 1 (1986), pp 37-50.

Differences in soil surface properties were measured on soil cores collected from within tracks and adjacent undisturbed areas. The passage of tracks resulted in an increase in bulk density, a reduction in saturated hydraulic conductivity and an increase in cone penetrometer resistance. Laboratory direct shear tests showed in track soil were stronger than out-of-track samples. The saturated hydraulic conductivity of in-track soil cores increased with an increasing number of wetting and draining cycles, whereas out-of-track samples showed little change. Implications for erosion, vegetation regeneration and management strategies for off-road vehicle areas are discussed, with some speculation as to the rate of recovery of impacted areas.

37. Buchkina, N.P., V.S. Zuyev, and E.V. Balashov, "Effects of tracked vehicles on the morphological and physical properties of tundra soils," *Soil & Tillage Research*, vol 48, no. 4 (1997), pp 317-324.

The agricultural lands of typical tundra of the Yamal Peninsula in Russia are pastures for reindeer (*Rangifer tarandus sibiricus* Murr.) herds. Currently, degradation of tundra soil cover is mainly caused by mechanical impacts of tracked vehicles used in construction operations. The objective of this study was to evaluate changes in morphological, micro-structural, and physical properties of Cryozems and Cryogenic peaty soils affected by these tracked vehicles. Soil samples were taken from the surface and underlying horizons before and 5 years after 4 and 100 passes of tracked vehicles. Surface horizons (0-10 cm) of the undisturbed Cryozems and Cryogenic peaty soils were organogenic. Passage of tracked vehicles caused mixing of these horizons with lower sandy loam and loam mineral horizons. Properties of the organomineral horizons formed in this

way differed essentially from those of the surface horizons of the undisturbed soils. Microaggregates were completely disturbed, even after only four passes of tracked vehicles. Large inter-aggregate pores disappeared and thin pores or cracks formed as a result of vehicle-induced mechanical impacts. Humification of plant residues was observed to be faster in the compacted organomineral horizons of disturbed soils compared with undisturbed ones. The organic substances formed in the compacted organomineral horizons readily moved downward within the soil profile or were lost during runoff events. High correlation coefficients of organic carbon content with both specific surface area and water retention showed that the above-mentioned organic substances were hydrophilic. Specific surface area and water retention of the disturbed soils rose with increasing organic carbon content. The results obtained in this study demonstrated a high susceptibility of Cryozems and Cryogenic peaty soils to mechanical impacts.

38. Burger, J.A., J.V. Perumpral, R.E. Kreh, J.L. Torbert, and S. Minaei, "Impact of Tracked and Rubber-tired Tractors on a Forest Soil," *Transactions of the ASAE*, vol 28, no. 2 (1985), pp 369-373.

Despite a three-fold difference in contact pressure, changes in soil density and porosity caused by an unloaded, rubber-tired log skidder did not exceed those caused by a crawler. The changes in soil density and porosity caused by these machines increased with soil moisture content. Changes in soil density and porosity increased proportionally with the square root of the number of passes over the same area.

39. Burger, J.A., J.V. Perumpral, R.E. Kreh, J.L. Torbert, and S. Minaei, "The Effect of Track and Rubber-Tired Vehicles on Soil Compaction," *Transactions of the ASAE*, microfiche number 83-1621, (1983).

Despite a three-fold difference in contact pressure, changes in soil density and porosity caused by an unloaded, rubber-tired log skidder did not exceed those caused by a crawler. The changes in soil density and porosity caused by these machines increased with soil moisture content. Changes in soil density and porosity increased proportionally with the square root of the number of passes over the same area.

40. Challinor, J.L. and P.L. Gersper, "Vehicle Perturbation Effects upon a Tundra Soil-Plant System: II. Effects on the Chemical Regime," *Soil Science Society of America Proceedings*, vol 39 (1975), pp 689-695.

Chemical regime alterations of a soil-plant system resulting from tracked-vehicle perturbation were determined in Tundra soils near Barrow, Alaska. The study was a contribution to the U.S.B.I.P. Tundra Biome Program. Six years following perturbation, soils within track scars had lower redox potentials (negative) and lower amounts of exchangeable acidity than undisturbed soils. Furthermore, exchangeable bases (Ca, Mg, K, and Na) were higher in the track-influenced soils. Consequently, soil pH and base saturation were also higher. Soluble nutrient (Ca, Mg, K, Na, and NH4-N) levels in soil solutions were considerable higher in track-influenced soils than in undisturbed soils. Correspondingly, soil solution pH was also higher. Plants growing in the altered environment of the track scars were enriched in nutrients and were larger in size. Increased productivity and quality of track-influenced vegetation was apparently stimulated by an increase in available nutrients in less acid, warmer, nutrient enriched soils. The track perturbation also resulted in changes in floristic composition of the vegetation at different locations within track-affected soils. The intensity of soil alteration and resulting changes in the soil-plant chemical regime were related to the degree of scarring of the landscape which, in turn, was related to differences in the natural drainage of soils along the tracks; scarring being greater, the poorer the natural drainage. Results show that a slight amount of disturbance to the tundra surface may be beneficial in terms of increased productivity and nutrient content of vegetation.

41. Diersing, V.E., R.B. Shaw, S.D. Warren, and E.W. Novak, "A Users Guide for Estimating Allowable Use of Tracked Vehicles on Non-wooded Military Training Lands," *Journal of Soil and Water Conservation*, vol 43, no. 2 (1988), pp 191-195.

To avoid excessive soil erosion and ensure the continued availability of U.S. military training lands, there must be a basis for estimating allowable levels of sustained tracked vehicle use. The allowable use management objective can be attained by establishing permanent line transects in areas representative of each ecological response unit. The point-intercept method is employed along each line transect to determine botanical composition, amounts of ground and canopy cover for untracked and tracked points, and percent of the surface tracked and untracked. Soil samples are collected to determine soil erosibility. Slope lengths and gradients are measured. For each vehicle type, estimates are made of the average cross-country distance traveled per day (surface coverage is computed by adding the width of the tracks times distance traveled). Estimates are made of

the average number of years for tracked areas to regrow vegetation cover equivalent in C-value for the universal soil loss equation to untracked areas and the average number of years that a track mark remains visible. With this information and using the USLE, maximum allowable use can be estimated for each ecological response unit. Allowable use is calculated in tracked vehicle days per year (TVDs/year) for military trainers and percent surface disturbance for land manager. Land managers verify that allowable use is not exceeded by measuring the percentage of the surface that appears tracked. Adjustments in allowable use are based on trends in the amount of ground cover (detected by short-term monitoring) and by observing changes in botanical composition (detected by long-term monitoring).

42. Diersing, V.E., R.B. Shaw, and D.J. Tazik, "U.S. Army Land Condition Trend Analysis (LCTA) Program," *Environmental Management*, vol 16, no. 3 (1992), pp 405-414.

The U.S. Army Land Condition-Trend Analysis (LCTA) program is a standardized method of data collection, analysis, and reporting designed to meet multiple goals and objectives. The method utilizes vascular plant inventories, permanent field plot data, and wildlife inventories. Vascular plant inventories are used for environmental documentation, training of personnel, species identification during LCTA implementation, and as a survey for state and federal endangered or threatened species. The permanent field plot data documents the vegetational, edaphic, topographic, and disturbance characteristics of the installation. Inventory plots are allocated in a stratified random fashion across the installation utilizing a geographic information system that integrates satellite imagery and soil survey information. Ground cover, canopy cover, woody plant density, slope length, slope gradient, soil information, and disturbance data are collected at each plot. Plot data are used to: (1) describe plant communities, (2) characterize wildlife and threatened and endangered species habitat, (3) document amount and kind of military and nonmilitary disturbance, (4) determine the impact of military training on vegetation and soil resources, (5) estimate soil erosion potential, (6) classify land as to the kind and amount of use it can support, (7) determine allowable use estimates for tracked vehicle training, (8) document concealment resources, (9) identify lands that require restoration and evaluate the effectiveness of restorative techniques, and (10) evaluate potential acquisition property. Wildlife inventories survey small and midsize mammals, birds, bats, amphibians, and reptiles. Data from these surveys can be used for environmental documentation, to identify state and federal endangered and threatened species, and to evaluate the impact of military activities on wildlife populations. Short- and long-term monitoring of permanent field plots is used to

Short- and long-term monitoring of permanent field plots is used to evaluate and adjust land management decisions.

43. Felix, N.A. and M.K. Raynolds, "The Effects of Winter Seismic Trails on Tundra Vegetation in Northeastern Alaska, U.S.A.," *Arctic and Alpine Research*, vol 21, no. 2 (1989), pp 188-202.

The effects of winter seismic trails on tundra vegetation were studied on the Coastal Plain of the Arctic National Wildlife Refuge. Seismic exploration occurred during the winters of 1984 and 1985. Thirty-four permanent study plots were established the following summers, representing the range of disturbance, which occurred in each of seven major vegetation types. Plots were visited two of the first three summers after disturbance. At each plot plant cover was measured using a point frame, disturbance characteristics were recorded, and ground surface elevation were surveyed. Plant cover was lower on most disturbed plots than on their adjacent controls, with decreases as high as 87% the first summer following disturbance. The species most sensitive to disturbance were evergreen shrubs, followed by willows, tussock sedges, and lichens. Willow height in riparian shrubland plots was significantly reduced by 5 to 11 cm (from an average of 16 cm, $P < 0.05$). Little recovery of plants occurred in the second or third summers after disturbance; only four plots in river floodplain habitats (Dryas terrace and riparian shrubland) showed improvements in cover of a few species. Track depressions ranging from 5 to 15 cm occurred at three plots in moist sedge-shrub tundra and increased significantly ($P < 0.05$) at one plot between the first and third summers following disturbance. Continuation of this study will provide information on the long-term impacts and recovery rates of winter seismic trails.

44. Felix, N.A., M.K. Raynolds, J.C. Jorgenson, and K.E. Dubois, "Resistance and Resilience of Tundra Plant Communities to Disturbance by Winter Seismic Vehicles," *Arctic and Alpine Research*, vol 24, no. 1 (1992), pp 69-77.

Effects of winter seismic exploration on arctic tundra were evaluated on the coastal plain of the Arctic National Wildlife Refuge, four to five growing seasons after disturbance. Plant cover, active layer depths, and track depression were measured at plots representing major tundra plant communities and different levels of initial disturbance. Results are compared with the initial effects reported earlier. Little resilience was seen in any vegetation type, with no clearly decreasing trends in community dissimilarity (differences in species cover values between disturbed and control areas). Active layer depths remained greater on plots in all nonriparian vegetation types, and most plots still had visible trails. Decreases in plant cover persisted on most plots, although a few species showed

recovery or increases in cover above predisturbance level. Moist sedge-shrub tundra and dryas terraces had the largest community dissimilarities initially, showing the least resistance to high levels of winter vehicle disturbance. Community dissimilarity continued to increase for five seasons in moist sedge-shrub tundra, with species composition changing to higher sedge cover and lower shrub cover. The resilience amplitude may have been exceeded on four plots, which had significant track depression.

45. Frid, C.L.J., W.U. Chandrasekara, and P. Davey, "The Restoration of Mud Flats Invaded by Common Cord-grass (*Spartina anglica*, CE Hubbard) Using Mechanical Disturbance and its Effects on the Macrobenthic Fauna," *Aquatic Conservation-Marine and Freshwater Ecosystems*, vol 9, no. 1, (1999), pp 47-61.

The growth of the common cord-grass, *Spartina anglica*, across many temperate coastlines has resulted in a reduction in the extent of tidal flats. Its colonization has reduced the abundance of macrobenthic fauna and hence has had a direct effect on the feeding of shorebirds. Although the use of chemical methods has proven successful in controlling *Spartina* swards on tidal flats, factors such as environmental and human health concerns have stimulated a search for alternative control methods. However, any such control method must not impact the macrobenthic fauna. The effectiveness of a physical disruption to control *Spartina* swards on tidal flats was investigated in the salt marsh at Lindisfarne NNR, UK. The sediment was disturbed by a light-weight tracked vehicle until the *Spartina* swards were dislodged and buried within the sediment. The post-disturbance dynamics of the infauna in the disturbed area was investigated 1, 12, 31, 92, and 384 days after the disturbance. In spite of the drastic change brought about in the flora, there was no evidence that the infauna were impacted by the disturbance at any sampling time. Two possible mechanisms to explain the absence of changes in the abundance of the infauna are discussed with special reference to the unconsolidated nature of the sediment and the high mobility of the adult infauna. The abundance of *Spartina* swards in the disturbed area was lower than that in the undisturbed area. Physical disturbance to *Spartina* swards by the tracked vehicle seems to be an appropriate method for its control in tidal flats, which obviates the need, with associated financial costs and environmental risks, of chemical control.

46. Gatto, L.W., *Ground Freezing Effects on Soil Erosion of Army Training Lands. Part 1: Initial Test Results.* Special Report 97-15, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), (1997).

Military maneuvers damage vegetation and compact and rut soils on training lands, thereby increasing the likelihood of hillslope runoff and soil erosion. Soil Freeze-Thaw (FT) processes can change the hydraulic geometry and roughness of vehicle ruts and reduce soil compaction, which often partially restores the water infiltration rate that existed before compaction. The efficiency of these FT-induced "repairs" depends on soil water content and FT intensity. Initial tests showed that (1) an experimental soil bin designed and constructed for rut experiments allows acceptable simulation of field soil FT, and (2) the hydraulic geometry of a rectangular rill in a fine silt soil with an initial volumetric water content of 36% changes dramatically due to rill sideslope slumping during thaw. Future experiments will compare differences in the response of natural rills and vehicle ruts to FT-induced soil failure, and investigate the effects of FT on soil erodibility and the influences of snow cover on soil erosion processes in the spring.

47. Gersper, P.L. and J.L. Challinor, "Vehicle Perturbation Effects upon a Tundra Soil-Plant System: I. Effects on Morphological and Physical Environmental Properties of the Soils," *Soil Science Society of America Proceedings*, vol 39 (1975), pp 737-744.

Changes obtaining in the soil abiotic physical environment due to tracked-vehicle disturbance were determined in Tundra soils near Barrow, Alaška. The study was a contribution of the U.S.I.B.P., Tundra Biome Program. Six years following the scarring of the tundra surface by several years of infrequent passage by tracked-vehicles (Weasel), the soils within the track had higher bulk densities and temperatures, accelerated and deeper thaw, and lower moisture percentages than undisturbed soil. Soil morphology was little altered except for the direct physical alteration of surface organic horizons and a slight increase in mottling of mineral horizons in all but the wetter portions of the track. The intensity of alteration and associated environmental changes were related to the degree of evident disturbance (the amount of visible damage to the vegetation cover and soil surface) which, in turn, were related to differences in the natural drainage of the soils along the tracks: disturbance being greater, the poorer the natural drainage. The study indicated that a slight amount of disturbance to tundra surface may be beneficial in terms of increased productivity and nutrient content of vegetation. On the other hand, heavy disturbance can result in severe

damage to the tundra system due to subsidence and erosion preventing the revegetation of the disturbed areas.

48. Halvorson, J.J., D.K. McCool, L.G. King, and L.W. Gatto. *Ground Freezing Effects on Soil Erosion of Army Training Lands. Part 2: Overwinter Changes to Tracked-Vehicle Ruts, Yakima Training Center, Washington*. Special Report 98-8, U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory, (1998).

Two areas were monitored at the Yakima Training Center (YTC) in central Washington to measure changes in M1A2 Abrams (M1) tank-rut surface geometry and in- and out-of-rut saturated hydraulic conductivity (K_{fs}), soil penetration resistance (SPR), and bulk density over the 1995-1996 winter. Profile meter data show that rut cross-sectional profiles smoothed significantly and that turning ruts did so more than straight ruts. Rut edges were zones of erosion and sidewall bases were zones of deposition. K_{fs} values were similar in and out of ruts formed on soil with 0-5% water by volume, but were lower in ruts formed on soil with about 15% water. Mean SPR was similar in and out of ruts from 0- to 5-cm depth, increased to 2 MPa outside ruts and 4 MPa inside ruts at 10- to 15-cm depth, and decreases by 10-38% outside ruts and by 39-48% inside ruts at the 30-cm depth. Soil bulk density was similar in and out of ruts from 0 to 2.5-cm depth, and below 2.5-cm it was generally higher in ruts formed on moist soil, with the highest values between 10- and 20-cm depth. Conversely, density in ruts formed on dry soil was similar to out-of-rut density at all depths. This information is important for determining impacts of tank ruts on water filtration and soil erosion and for modifying the Revised Universal Soil Loss Equation (RUSLE) and the Water Erosion Prediction Project (WEPP) models to more accurately predict soil losses on Army training lands.

49. Halvorson, J.J., D.K. McCool, L.G. King, and L.W. Gatto. "Soil compaction and over-winter changes to tracked-vehicle ruts, Yakima Training Center, Washington." *Journal of Terramechanics*, vol 38, no. 3 (2001) pp 133-151.

We monitored two areas at the Yakima Training Center (YTC) in central Washington to measure changes in M1A2 Abrams (M1) tank-rut surface geometry and in- and out-of-rut saturated hydraulic conductivity (K_{fs}), soil penetration resistance (SPR), and soil bulk density (BD). Profile-meter data show that rut cross-sectional profiles smoothed significantly and that turning ruts did so more than straight ruts. Rut edges were zones of erosion and sidewall bases were zones of deposition. K_{fs} values were similar in and out of ruts formed on soil with 0-5% moisture by volume, but were lower in ruts formed on soil with about 15% water.

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50. Kreh, R.E., J.A. Burger, and J.L. Torbert, *Soil compaction from tracked and rubber-tired tractors and its influence on seedling survival and growth*, Report 54, Forest Service General Technical Report, SO. U.S. South Forest Experiment Station, New Orleans, LA. (1985).

The effect of multiple passes of tracked and rubber-tired harvesting and site preparation equipment, operating under known soil moisture conditions, on tree survival and growth after two growing seasons was evaluated. A skidder and crawler compacted the soil to the same extent despite differences in contact pressure. The number of passes over the same area did not affect survival, but volume was reduced by 34% after one pass and 54% after nine passes. Higher soil moisture resulted in higher compaction, but growth was not significantly affected.

51. Price, D.L., A.B. Anderson, P.J. Guertin, T. McLendon, and W.M. Childress, *The U.S. Army's Land-Based Carrying Capacity*. Technical Note 97/142, U.S. Army Construction Engineering Research Laboratory (1997).

The Army's interest in land management began with a need to manage and sustain the natural resources in its care. The notion of "carrying capacity" arose from the significant overlap between the responsibility to maintain natural resources (environmental stewardship) and the Army trainers' need for well maintained land for use in training exercises. This coincidence of needs has matured the concept of carrying capacity into a comprehensive programmatic approach to land management that yields both environmental and practical benefits.

This technical note conceptually frames the Army's requirement for land-based carrying capacity and the capability being developed to address this need. It documents both the problem of land management as related to land-based carrying capacity, and the historical efforts to address the problem. The authors dis-

cuss the logical progression from exploratory and qualitative research efforts to bound the problem, to the development of more sophisticated and quantitative efforts to determine cause-and-effect relationships. Later efforts have focused on capturing these data and relationships within predictive simulation models. The authors then describe the various pieces that have been developed, evolved, and experimentally applied; how those pieces fit to become the whole; and how the whole or the pieces can be accepted and used. Finally, they identify short- and long-term knowledge gaps and technical issues that are being addressed.

52. Rickard, W.E. Jr. and J. Brown, "Effects of Vehicles on Arctic Tundra," *Environmental Conservation*, vol 1, no. 1 (1974), pp 55-62.

The traditional form of transportation in the tundra has always been, of necessity, cross-country or off-road. A variety of tracked off-road vehicles have been used over the past several decades for travel across tundra. Within the past several years, other vehicles have been introduced and are still undergoing evaluation. Travel in the Arctic is nowadays predominantly by aircraft or by specifically designed overland vehicles, including the air-cushion vehicle (ACV) and smooth-wheeled vehicles. This report reviews the state of knowledge and interpretation concerning the environmental impact or disturbance of vehicular traffic on tundra. Emphasis is on known experimental test-sites and accounts of recovery from disturbances in the American arctic tundra.

Terrain damage resulting from off-road vehicular movement in arctic areas is potentially serious — particularly in the wetter, ice-rich permafrost terrain. The most dramatic and adverse effect of off-road traffic on tundra is the disruption of the surface organic layer, which results in the accelerated thaw of permafrost. Detailed examination of vehicle trails made in the 1940s indicate that natural recovery and stabilization of these trails has been relatively slow. Several recent controlled tests using a variety of vehicles suggest that long-term impact of vehicles on the terrain is a function of time of year, type of substrate, vegetation, soil moisture, ground-contact pressure, type of vehicle propulsion (i.e., tracks, air cushion, etc.) and operator technique.

53. Sample, L.J., J. Steichen, and J.R Kelley, "Water quality impacts from low water fords on military training lands," *Journal Of The American Water Resources Association,* vol 34, no.4, (1998), pp 939-949.

Water quality impacts from two types of low water stream crossings (LWSC) were examined on the military training lands at Fort Riley, Kansas. The LWSC project was developed to enhance military training as well as improve the water

quality of the streams. Water quality impacts of low water fords were quantified and compared to determine the effects of using rock to harden earthen fords. Both earthen and rock-hardened low water fords were tested for the impact on stream turbidity, total solids, total dissolved solids, total suspended solids, and settleable solids. Results indicate hardening earthen fords with rock can significantly reduce water quality degradation caused by vehicle movement over the ford. Turbidity caused by vehicles crossing earthen and hardened fords was nearly sixteen times higher for earthen fords. Likewise, total solids, total dissolved solids, and total suspended solids concentrations were lower for hardened crossings. Total solids concentrations from earthen fords were nearly twelve times higher than concentrations from hardened fords. Hardening earthen fords not only provides the military with a more stable stream crossing for its soldiers to use, it decreases water quality degradation and improves local stream ecology. Recommendations for constructing rock hardened LWSC are given.

54. Shaw, R.B. and V.E. Diersing, "Allowable Use Estimates for Tracked Vehicular Training on Pinon Canyon Maneuver Site, Colorado, USA," *Environmental Management*, vol 13, no. 6 (1989), pp 773-782.

A method is presented for calculating allowable use of tracked vehicles on the U.S. Army's Pinon Canyon Maneuver Site in southeastern Colorado. The first step in this process is to determine the sheet and rill erosion rate on each soil series using the Revised Universal Soil Loss Equation. Soil series are then ranked according to their trainability (e.g., ranked based on how much vegetation cover can be lost without exceeding soil loss tolerance). Maximum onetime surface use, allowable surface user year, usable hectares per year, and tracked vehicle days per year can then be calculated. Examples are given to illustrate how these values can be manipulated to assist land managers and military trainers to better plan and match training missions to available land. Also, short- and long-term monitoring schemes are presented that can be used to verify or adjust estimates of allowable use. The methods presented can converted to determine allowable use of other types of activities that disturb the vegetation and expose the soil surface to the erosive forces of wind and water (e.g., recreational and off-road vehicles).

55. Steenhof, K., M.N. Kochert, L.B. Carpenter, and R.N. Lehman, "Long-term Prairie Falcon Population Changes in Relation to Prey Abundance, Weather, Land uses, and Habitat Conditions," *Condor*, vol 101, no. 1 (1999), pp 28-41.

We studied a nesting population of Prairie Falcons (*Falco mexicanus*) in the Snake River Birds of Prey National Conservation Area (NCA) from 1974-1997 to

identify factors that influence abundance and reproduction. Our sampling period included two major droughts and associated crashes in Townsend's ground squirrel (*Spermophilus townsendii*) populations. The number of Prairie Falcon pairs found on long-term survey segments declined significantly from 1976-1997. Early declines were most severe at the eastern end of the NCA, where fires and agriculture have changed native shrubsteppe habitat. More recent declines occurred in the portion of canyon near the Orchard Training Area (OTA), where the Idaho Army National Guard conducts artillery firing and tank maneuvers. Overall Prairie Falcon reproductive rates were tied closely to annual indexes of ground squirrel abundance, but precipitation before and during the breeding season was related inversely to some measures of reproduction. Most reproductive parameters showed no significant trends over time, but during the 1990s, nesting success and productivity were lower in the stretch of canyon near the OTA than in adjacent areas. Extensive shrub loss, by itself, did not explain the pattern of declines in abundance and reproduction that we observed. Recent military training activities likely have interacted with fire and livestock grazing to create less than favorable foraging opportunities for Prairie Falcons in a large part of the NCA. To maintain Prairie Falcon populations in the NCA, managers should suppress wildfires, restore native plant communities, and regulate potentially incompatible land uses.

56. Sullivan, P.M. and A.B. Anderson, *A Methodology for Estimating Army Training and Testing Area Carrying Capacity (ATTACC) Vehicle Severity Factors and Local Condition Factors*. ERDC Technical Report 00-2, U.S. Army Engineer Research and Development Center (2000).

The Army Training and Testing Area Carrying Capacity (ATTACC) program is a methodology for estimating training and testing land carrying capacity. The methodology is used to determine land rehabilitation and maintenance costs associated with land-based training. ATTACC is part of the Army's Integrated Training Area Management Program. The ATTACC methodology quantifies training load in terms of Maneuver Impact Miles (MIM), which are based on vehicle mileage projections. Each vehicle in each training event has a different impact on the land. To account for these differences, all training events are normalized to a standard unit in a standard event. The ATTACC standard is the M1A2 in an armor battalion in a field training exercise (FTX). Training impact factors represent the difference in impact between vehicles and events compared to the standard. The factors used to calculate MIM are Vehicle Severity Factors (VSF), Event Severity Factors (ESF), Vehicle Conversion Factors (VCF), Vehicle Off-Road Factors (VOF), and Local Condition Factors (LCF). Vehicle Severity Factors account for the differences in impacts due to different types of vehicles.

Local Condition Factors account for differences in vehicle impacts due to weather variations. This report documents a methodology for estimating ATTACC vehicle severity and local condition factors. The methodology is based on reanalysis of data and models used in the NATO Reference Mobility Model.

57. Tucker, J.L., D.B. Rideout, and R.B. Shaw, "Using linear programming to optimize rehabilitation and restoration of injured land: an application to U.S. Army training sites," *Journal of Environmental Management*, vol 52, no. 2, (1998), pp 173-182.

Rehabilitating damaged lands is often necessary to repair environmental damage from natural and man-induced activities. Damage and its rehabilitation present a trade-off in cost where increasing rehabilitation costs reduce the cost of damage. To manage this trade-off a Linear Program (LP) was formulated to minimize the cost of rehabilitation plus damage. The cost minimization techniques were applied to the Fort Carson Military Reservation in Colorado. This fort sustains heavy military training activity and is characterized by diverse terrain and complex vegetation. Data were obtained from site assessments and interviews with land managers, rehabilitation cost information was used to arrive at five treatment alternatives available for each acre identified as needing rehabilitation. The program identified the optimal treatment schedule given limited resources including budget and three kinds of land; grassland, shrubland and woodland. The results suggest that such LP formulations can provide an important tool for military land managers seeking cost-effective rehabilitation of their sites. The LP application provided an insightful and convenient way to optimize the schedule of treatments that would minimize total cost across the different cover types while producing ancillary output on the value of additional budget and land. The process has potentially broader appeal as a tool to guide land managers in the optimal allocation of rehabilitation resources.

58. Turner, J.L., "A Semi-Empirical Mobility Model for Tracked Vehicles," *Transactions of the ASAE*, vol 27, no. 4 (1984), pp 990-996.

A combined empirical-finite element approach to tracked vehicle-soil modeling is described. Comparison with experiments for tracked vehicle operation on quarry sand is given. The model is shown to predict slip-pull performance with reasonable accuracy for these conditions. The model is used to demonstrate the effect of drawbar and center of gravity positioning on vehicle pull performance and ground pressure distributions.

59. Tweddale, Scott A. Charles L. Echschlaeger, and William F. Seybold, *An Improved Method for Spatial Extrapolation of Vegetative Cover Estimates (USLE / RUSLE C Factor) Using LCTA and Remotely Sensed Imagery*, USAEC Report SFIM-AEC-EQ-TR-200011 and ERDC/CERL TR-00-7, June 2000.

The Army Training and Testing Area Carrying Capacity (ATTACC) methodology has been developed to characterize and quantify the capability of Department of Defense (DoD) lands and natural resources to support military training and testing missions on a sustained basis. The ATTACC methodology uses erosion status as a metric to assess current land condition and to predict changes in land condition based on proposed training loads. ATTACC currently uses components of both the Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) for estimating average annual soil loss. Vegetative cover has been identified as a critical factor for estimating erosion, and both the USLE and the RUSLE require estimates of vegetative cover to estimate erosion protection afforded by various vegetative covers. Currently, ATTACC uses vegetative cover (the C factor) as defined by USLE, but uses other factors as defined by RUSLE.

The objective of this research effort was to demonstrate this alternative method for extrapolating vegetative cover estimates from point data to larger geographic areas and to compare and contrast this method with current methods for spatial extrapolation of vegetative cover estimates. Fort Hood, TX was chosen as the site to demonstrate both methods. The implications associated with using each method of spatial extrapolation of cover estimates in terms of evaluating both soil erosion potential using USLE and RUSLE, and indirectly, carrying capacity using ATTACC, are discussed. However, this research was not intended to evaluate the accuracy of erosion status estimates derived from either soil loss model (USLE or RUSLE), but rather to evaluate two alternative methods for spatial extrapolation of C-factor values from point data collected in the field. The results are presented from the perspective of an installation land manager who is most concerned with areas of high C factor, or low vegetative cover, on a military installation.

Results indicate that the demonstrated alternative method, which uses regression analysis with remotely sensed vegetation indices, addresses both identified shortcomings of the current method for extrapolating the USLE C factors. First, the alternative or regression method provides estimates for areas of an installation that were not sampled or were undersampled. Second, the C-factor map created from regression analysis provides ratio estimates of the C factor, thereby capturing the spatial variability in vegetative cover that occurs within unsupervised image classes or mapping units. This process resulted in superior statistical precision in C-factor es-

timates across the installation. The mean C-factor map derived from the current spatial extrapolation method was less able to differentiate between high and low C-factor soil erosion potential. The mean C-factor map derived from the alternative extrapolation method was able to capture and delineate more heterogeneity in the C factor, thereby enabling land managers to identify areas of varying C factor. For these reasons, the regression analysis approach, whereby ground measurements of the C factor are correlated with vegetation indices from spectral imagery and then used to extrapolate C-factor estimates, is recommended as an improved method for extrapolating vegetative cover (C-factor) estimates across military installation lands.

60. Whitecotton, R.C.A., M.B. David, R.G. Darmody, and D.L. Price, "Impact of Foot Traffic from Military Training on Soil and Vegetation Properties," *Environmental Management*, vol 26, no. 6 (2000), pp 697-706.

The impact of military training activities (primarily foot traffic) on soils and vegetation was assessed at the United States Air Force Academy, Colorado, USA. In May-June 1998 after 2 years of intensive training use, mean bulk densities of the top 6 cm of soil in the high-use site (1.37 g/cm^3) and moderate-use site (1.30 g/cm^3) were significantly different from bulk density of the reference site (1.04 g/cm^3). Mean infiltration rates on the high use site (0.63 cm/min) and moderate use site (0.67 cm/min) were significantly different from the infiltration rate on the reference site (3.83 cm/min). Soil water holding capacities of the three sites were not significantly different. Descriptive comparisons of total aboveground biomass and litter indicated a 68% decrease in total aboveground biomass and a 91% decrease in litter when the high-use site was compared to the reference site. Using the Universal Soil Loss Equation, an estimated soil erosion rate for the reference plot (0.07 tons/ha/yr) was 30 times less than the erosion rate for the high use plot in the center of the basic cadet training encampment area (2 tons/ha/yr) and between 7 and 6 times less than the moderate use plot and the high use plot on the edge of the encampment area (0.5 and 0.4 tons/ha/yr, respectively). Therefore, training use appears to adversely affect bulk density, infiltration, total aboveground biomass, litter, and erosion. Without implementation of restoration practices, further site degradation is likely

61. Yorks, T.P., N.E. West, R.J. Mueller, and S.D. Warren, "Toleration of Traffic by Vegetation: Life Form Conclusions and Summary Extracts from a Comprehensive Database," *Environmental Management*, vol 21, no. 1 (1997), pp 121-131.

An exhaustive search of the literature for foot and vehicle traffic damage to vegetation has yielded >400 citations, two-thirds of which held sufficient detail to be included in a consistent PC database. A total of 1444 individual observations

involving 737 species that were trampled are included. Compromises were made in the depth of entry detail to allow comparability among data. Inconsistent, generally short-term, experimental practices disallowed formal statistical analyses. Within those constraints, graminoids emerged with the highest mean resistance and resilience among life-forms. Climbers and cactoids ranked lowest in these categories. The herbaceous, typically broad-leaved, life-form appeared most likely to suffer immediate losses. Shrubs and trees had the longest-lasting reductions in diversity following trampling. All life-forms had sensitive species. The greatest general losses of species and individual plants occurred in the first few passes by feet, wheels or tracks. Plant and soil damage increases with the amount of weight and power applied. Greater soil moisture and/or deeper overstory shading magnify those impacts. Additional precepts may become apparent to data-base users through increased ease in making comparisons.

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14. ABSTRACT

Vehicle impacts are an important military training issue because, in order to adequately train for combat, military training must occur in all weather conditions and at all times of the year. Vehicles must be allowed to maneuver over terrain and distances similar to what is expected in a battlefield environment. These training activities must be balanced with legal requirements pertaining to natural resources protection (Endangered Species Act, Clean Water Act, etc.) and the need to sustain the condition of the land to support military training over the long term.

This bibliography focuses on identifying the information available for military impacts on vegetation as distinct from those concerning air quality, water quality, noise pollution, soil contamination, and direct impacts on animals. The available literature on impacts of military vehicles on military lands was surveyed. The bibliography has been divided into two parts: (1) military references developed from military vehicles or military lands and representing primary observations or research, and (2) supporting references that were not developed from the military but which have applicability to training activities on military lands by military vehicles or are derivative from primary works on the military. This report contains 61 references with abstracts.

15. SUBJECT TERMS

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